DOCUMENT RESUME

ED 224 994 CE 034 870

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TITLE Developing a Comprehensive and Articulated Nuclear Training Curriculum--The Westinghouse Model.
PUB DATE [Dec 82]
NOTE 16p.; Presented at the American Vocational Education Convention (St. Louis, MO, December 1982).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Articulation (Education); Behavioral Objectives; Classification; *Competency Based Education; Course Descriptions; Curriculum Development; *Energy Occupations; *Industrial Education; Instructional Materials; Instructional Systems; Material Development; Models; *Nuclear Energy; Nuclear Power Plants; Nuclear Power Plant Technicians; Postsecondary Education; Power Technology; Task Analysis; Technical Education
IDENTIFIERS *Energy Education; *Westinghouse Nuclear Training Center IL

ABSTRACT

After conducting a comprehensive evaluation of its curriculum, staff at the Westinghouse Nuclear Training Center in Zion, Illinois, undertook a research and development project aimed at upgrading the center's curriculum to the competency-based format. Included among the main activities of the curriculum development process were the following: completion of a study to identify the tasks performed by practicing reactor operators, identification of appropriate educational domains and taxonomies, development and sequencing of behavioral objectives, selection of a proper mode of instructional delivery, development of an effective format for curriculum materials, and evaluation of the effectiveness of the curriculum materials developed during the project. The project resulted in the development of an articulated curriculum consisting of three programs dealing with nuclear engineering technology, nuclear plant system design, and nuclear plant operations. For each separate program, instructional materials were developed that contained the following: objectives, lesson text, a summary, vocabulary, end notes, references, and a self-assessment instrument. After evaluating student performance on homework and examinations, analyzing utility training coordinator follow-up surveys, and considering the results of an external team review, researchers determined that the program has proven to be a successful means of preparing competent operations personnel. (MN)

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Developing a Comprehensive and Articulated Nuclear Training Curriculum - The Westinghouse Model

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ABSTRACT

Within recent years the nuclear power industry has undergone considerable growth and refinement, attributes which stem from concerted public and self evaluation. One key issue that has remained in the forefront of analysis and discussion is the issue of nuclear power plant personnel training. More specifically, the entire breadth and scope of reactor operator training has come under close scrutiny. Are the existing training procedures and programs meeting the needs of public safety and plant efficiency?

Similar to other industry factions, the Westinghouse Nuclear Training Center has conducted a careful and deliberate evaluation of its curriculum. In the final analysis, it was decided that a considerable amount of research and development was needed in order to upgrade the curriculum to the competency based format which is now the educational state-of-the-art. This paper describes the step-by-step process that Westinghouse Nuclear Training Center has undertaken in order to improve its overall curriculum. In brief, the process includes: conducting the task analysis; identifying the appropriate educational domains and taxonomies; writing behavioral objectives; sequencing the objectives; selecting the proper mode of instructional delivery; developing the unit of instruction; and evaluating the actual effectiveness of the curriculum product. As these tasks are conducted on a microscopic scale for discrete units of information, a macroscopic analysis is also being conducted to organize and sequence global topic areas, thus producing a comprehensive and articulated curriculum model.

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INTRODUCTION

Many years ago, the Chinese philosopher, Confucious, was credited with stating, "I hear and I forget, I see and I remember, I do and I understand." In more recent times, the highly acclaimed educator, John Dewey, has expounded upon this philosophy as evidenced in his publication, Experience and Education. In essence, Dr. Dewey has advocated that well structured learning experiences are compromised of both theory and application, i.e., classroom learning supplemented by hands-on practice.

Westinghouse Nuclear Training Services supports the rationale of these highly acclaimed educators and has attempted to develop a comprehensive and articulated curriculum based upon both theory and application. This paper explains the process of developing the actual curriculum materials and presents an overview of how theory and application are unified to form the courses and programs that constitute the overall curriculum model.

THE DEVELOPMENT PROCESS

The Westinghouse curriculum development process is comprised of seven sequential steps. A brief look at each of these steps is as follows.

Task Analysis - The task analysis study is a detailed listing of all of the tasks that the incumbent performs while on-the-job. In the case of Westinghouse Nuclear Training Center, all tasks performed by practicing reactor operators would be identified and listed.

The task analysis can be conducted in several different manners. For example, a trained educator could watch the job incumbent perform the job and then list all of the tasks performed by that individual. In the case of the nuclear industry, task analysis studies have been and are being conducted by watching reactor operators perform on shift as well as at simulated plant control boards. A second method of conducting a task analysis study is to assimilate

job incumbents and ask them to identify the tasks that they perform. Hence, groups of reactor operators have been and continue to be questioned regarding their job and task functions. A third way of conducting a task analysis study is to combine the aforementioned methods. In other words, observers would document specific tasks performed by job incumbents and later consult the job incumbents to verify and confirm the actual tasks that were documented. The Westinghouse task analysis study utilized this final approach, documenting tasks performed on the training simulator and later surveying students and instructors for concurrence and confirmation of the tasks identified.

Once a task listing has been identified and confirmed, each task listed can then be further described by identifying its frequency of performance, its relative importance in perspective to the entire job role, and its relative ease or difficulty regarding initial learning and mastery of the task. The model task analysis study, then, would represent a document similar to TABLE A.

TABLE A
SAMPLE TASK ANALYSIS

TASK	OVERALL IMPORTANCE	FREQUENCY	DIFFICULTY LEVEL FOR INITIAL LEARNING
A	Moderate	Daily	Simple
B	Extreme	Monthly	Difficult
C	Low	Hourly	Moderate
D	Moderate	Weekly	Very Difficult

Domains and Taxonomies of Learning - It is a proven fact that people learn in different manners. Benjamin Bloom (1956) receives credit for identifying three domains of learnining; cognitive, affective, and psychomotor. Cognitive learning encompasses those aspects of learning that one generally classifies as thinking and reasoning processes or skills. Affective learning encompasses beliefs, values, and attitudes. Psychomotor learning encompasses learned

manipulative or psychomotor skills. Finally, at a somewhat later date, Moore (1970) identified the perceptual domain which encompasses various perceptual skills and abilities.

Although the nuclear training field utilizes all four domains, it primarily focuses upon the cognitive domain. Bloom has broken the cognitive domain into a heirarchy of six levels, ranging from knowledge to evaluation. A brief description of the cognitive heirarchy is presented in TABLE B.

TABLE B

TAXONOMY OF THE COGNITIVE DOMAIN

Evaluation - decides, judges, or selects based on criteria or rationale

Synthesis - Combines elements to form a new entity

Analysis - separating the whole into its parts and analyzing relationships among elements

Application - Utilizing information in a situation different from original learning context

Comprehension - understanding, interpretation, or translation of information

Knowledge - knowledge, recognition, and recall of facts

(Bloom, 1956)

Note that the six levels of the taxonomy symbolically appear as stair steps. This signifies that one must first master or achieve all subsequent levels before attaining a higher level. That is to say, one does not just master synthesis; rather, one must master knowledge, comprehension, application, and analysis in that order before mastering synthesis.

Although the cognitive domain is of the most direct relevance to the nuclear trainer, the total curriculum encompasses the affective, psychomotor, and perceptual domains as well. Brief descriptions of the affective, psychomotor, and perceptual domains are contained in TABLES C, D, and E.

TABLE C

TAXONOMY OF THE AFFECTIVE DOMAIN

Characterizing - total behavior consistent with internal values

Organizing - Committed to a set of values as displayed by behavior

Valuing - displays behavior consistent with a single belief or attitude

Responding - complies to given expectations

Receiving - aware of and passively attending to stimuli; listening

(Krathwohl, 1964)

TABLE D

TAXONOMY OF THE PSYCHOMOTOR DOMAIN

Naturalization - completes one or more skills with ease to the point of being automatic

Articulation - combines more than one skill in a sequence with harmony and consistency

Precision - reproduces a skill with accuracy, proportion, and exactness

Maniuplation - performs skill according to instruction rather than observation

Initiation - observes skill and attempts to repeat

(Dave, 1970)

TABLE E

TAXONOMY OF THE PERCEPTUAL DOMAIN

Perceptive Performance - ability to make complex decisions via sensitive and accurate observation

Perception of Meaning - associating personal significance to forms and patterns

Symbol Perception - awareness of figures that form denotive signs

Figure Perception - sensory figure/ground perceptual organization

Sensation - detection and awareness of stimulus

(Moore, 1970)

The ultimate value of the aforementioned domains and taxonomies comes to fruition as the instructor/curriculum developer determines the appropriate domain or domains and corresponding levels for each task. That is to say, for each task identified in the task analysis, the curriculum developer can go on to decide which domains are applicable to which tasks. In addition, the curriculum developer can decide the appropriate level of desired student mastery for that task. For example, the task analysis data contained in TABLE A can then be expanded to resemble TABLE F.

TABLE F

TASK ANALYSIS WITH SUPPORTING DOMAINS

TASK	OVERALL IMPORTANCE	FREQUENCY	DIFFICULTY LEVEL	COGNITIVE	AFFECTIVE	PSYCHOMOTOR	PERCEPTUAL
A	Moderate	Daily	Simple	Comprehension	-	-	Symbol Perception
B	Extreme	Monthly	Difficult	-	Valuing	Manipulation	-
C	Low	Hourly	Moderate	Application	-	Articulation	Perception of Meaning
D	Moderate	Weekly	Very Difficult	Evaluation	Responding	-	Perceptive Performance

Thus, by marrying the documented tasks to the appropriate domains and applicable corresponding levels of the domains, the curriculum developer is essentially capable of determing what the student must do and to what level or degree the student must perform.

Behavioral and Performance Objectives - The essence of competency based education lies within the actual written and measurable objectives presented to the student. That is to say, the student, the instructor, and the public know from the onset what is expected of the student and what the student must demonstrate in order to attain competence. In all cases, the objective must be performance oriented, clearly stating measurable student behaviors and learning outcomes.

A good objective is comprised of four subparts: who does what how well under what conditions. In every case, who applies to the student. More specifically, competency based education does not care what the instructor will do, what the evaluator will do, what the lesson will do, or what the book will do; rather, its sole concern is for what the student will do. Secondly, the what of the objective always applies to the specified task as depicted in the task analysis. Thirdly, a good objective outlines the circumstances or given conditions needed in order to obtain the desired student behavior. For example, students may need control room simulators, technical specifications, or curve books in order to achieve the desired learning outcome. Finally, a good objective states how well the student will perform in order to achieve competence.

The bottom line is that good objectives eliminate speculation and guess work. Just like a good road map, a good objective allows one to know where he is going, how he is going to get there, and when he has arrived. In all cases, the student, the instructor, and the public know what is expected and what behaviors or performances were mastered in order to achieve competence. Good objectives result from the marriage of tasks and domain heirarchies. That is to say, when the curriculum developer knows what task must be mastered to what level of what domain, the actual objective almost writes itself.

TABLE G

SAMPLE OBJECTIVES ADDRESSING TURBINE THERMODYNAMICS

Upon completion of this chapter, the student will be able to:

- DEFINE, in his own words, the concept of entropy and give the mathematical expression relating entropy to heat and absolute temperature.
- DEFINE, COMPARE, and CONTRAST a reversible and irreversible process.
- GRAPH temperature vs. entropy and enthalpy vs. entropy for saturated water.

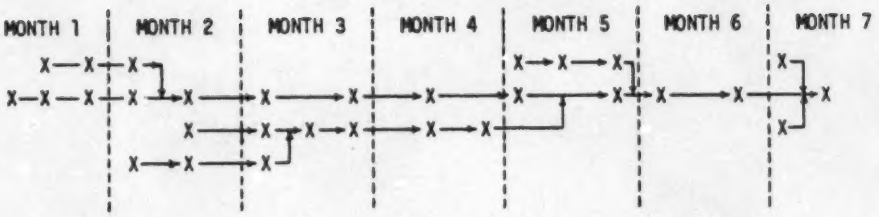
- GRAPH the Carnot cycle on a T-s diagram and DESCRIBE the areas of heat entering and leaving the system, the work done on and by the system, and the available and unavailable energy of the cycle.
- EVALUATE the thermal efficiency of a Carnot cycle.
- STATE the Second Law of Thermodynamics.
- SKETCH and DESCRIBE an ideal Rankine cycle on a T-s diagram, ILLUSTRATING Q_{in}, Q_{out}, W_{in}, and W_{out}.

Sequencing the Objectives - A well structured and articulated curriculum is somewhat like a pyramid, it continues to build subsequent knowledge upon previously laid foundations. There is a well sequenced and structured path that ultimately provides highly specialized and technical skills, all built upon prerequisite knowledge. Hence, the first and most important step in building this articulated curriculum model is to properly sequence the objectives.

Given that certain objectives will assuredly be prerequisites to others, an effective way of sequencing the objectives is via a PERT chart (PERT is an acronym representing Program Evaluation Review Technique). Another synonym for a PERT chart is a critical path chart. In essence, the curriculum developer must examine all of the objectives and determine 1) which objectives are prerequisites to other objectives, 2) which objectives have no bearing upon other objectives, and 3) which objectives may be delivered at relatively the same time as one another without impinging upon each other. When completed, the typical PERT chart may have a number of parallel paths, but only one critical path, which is the longest path toward completion. A sample PERT chart is represented in Figure 1.

FIGURE 1

SAMPLE PERT CHART



If the symbol X represents an objective, note that some objectives or chains of objectives are prerequisites to other objectives. Similarly, some objectives have tremendous flexibility in terms of the time range in which they can be delivered. Such objectives are ideal for self paced instruction or filling gaps in instructional delivery schedules. Finally, note that month 2 is an extremely critical month. Hence, particular emphasis must be placed upon student scheduling and instructor manpower loading.

Selecting the Appropriate Delivery Mode - Nuclear Trainers have a variety of instructional delivery modes to choose from. Some of the delivery modes available are presented in Table H.

TABLE H

ALTERNATIVE MODES FOR INSTRUCTIONAL DELIVERY

Simulator

Training Reactor

Small Scope Simulator

Computer Aided Instruction

Models

Plant Tours

Video Presentation

Slide Tape Presentation

Lecture

Peer Study/Role Play

Text Books

Note that as one reviews the alternatives listed in Table H in an ascending order, the alternatives generally become more powerful in instructional power and sophistication. A second way of saying this is that the higher level alternatives of Table H are more capable of meeting the higher levels of the various learning domains. That is, textbooks are ideal for meeting objectives that require knowledge and comprehension; but, in many cases, only a full scope simulator can foster synthesis and evalution. Also note that as one reviews the alternatives in Table H in ascending order, it becomes apparent that the cost of instructional delivery tends to increase. Hence, the essence of selecting the proper delivery mode is to choose the alternative that will master the objective at the lowest possible cost of instructional delivery. In most cases, an objective can be mastered through more than one option, but cost/benefit analyses must be conducted in order to select the most viable and efficient alternative.

Formatting the Curriculum Materials for Maximum Learning - Regardless of the delivery mode selected, learning can be enhanced by presenting the curriculum to the student in a logical, straight forward, and consistent format. Westinghouse has adopted and slightly modified a format developed by the National Center for Vocational Education and the Vocational-Technical Education Consortium of States. Choosing textbook research and development as an example, the format would be comprised of the following subcategories.

Objectives: Each chapter of the book would begin with a terminal objective, stating the overall student learning outcome for the chapter, and a series of enabling objectives, which represent smaller, more discrete learning behaviors enabling the student to meet the terminal objective.

Lesson Text: The actual lesson text delineates, in prose fashion, the required knowledges and skills necessary for the student to master the objectives. Similar to most textbooks, the lesson text is subdivided by topical headings, subheadings, and run-on headings.

Summary: The summary attempts to tie together or synthesize the material presented in the lesson text. When done effectively, the student understands precisely how a number of discrete knowledges and skills all tie together to crystallize the "big picture".

Vocabulary: The vocabulary section ties together in a direct and straight foward manner the technical terminology required of the student for that chapter. The vocabulary section takes on an even greater importance for the international student.

End Notes: The end notes describe, clarify, amplify, and/or supplement technical concepts presented in the text. The purpose of the end note is to provide increased scope and clarification without diverging from the central theme throughout the central body of the text.

References: The bibliography or references give credit to the authors and creators of specific concepts cited in the lesson text.

Self Assessment: The self assessment section contains a variety of questions and sample problems. All of the self assessment questions relate directly to the enabling objectives of the chapter.

Thus, by assigning some or all of the self assessment questions, both instructor and student can be assured that the objectives have been mastered.

Evaluating the Effectiveness of the Curriculum Material - The ultimate success or failure of any curriculum materials can only be determined by evaluation and feedback. This process is conducted in several manners: student performance on homework, student performance on examinations, student course critique feedback, utility training coordinator follow-up surveys, and external team review. Although not all of the Westinghouse curriculum has been upgraded to competency based instruction, the following insights have been noted in regard to those portions which are competency based.

- Students have a greater understanding of and appreciation for the learning outcomes expected of them.
- Homework and examination performance has improved.
- There appears to be an increasing consistency and uniformity in instructional delivery and content, regardless of the various presentation styles and philosophies of instructors.
- Utility training coordinator feedback has been favorable.
- External team review of the competency based education curriculum materials has been favorable. The American Council on Education has recommended that the Westinghouse competency based programs be accepted for college level credit.

THE CURRICULUM MODEL

An articulated program provides continuity, consistency, and interdependence between and among individual courses (Good, 1973). That is to say, the entire curriculum shows a logical and consistent continuity throught its courses and

programs. The Westinghouse reactor operator curriculum is comprised of three articulated programs. A brief description of each of these programs are as follows.

Nuclear Engineering Technology - The Nuclear Engineering Technology Program addresses the theoretical knowledges and skills necessary for safe and efficient plant operations. The program is comprised of six core courses addressing the topics of nuclear reactor theory; radioactivity, radiation detection, and radiation safety; large PWR core control; and heat transfer, fluid flow, and thermodynamics. These concepts are learned to the levels of application, analysis, synthesis, and application via hands-on training on the Westinghouse Nuclear Training Reactor (NTR). In essence, while operating the NTR, the students apply theories and formulas, learn radiation safety via handling fissionable material, and learn the fundamentals of operational procedures in an actual licensed facility. All in all, theory and application go hand in hand to provide the requisite fundamental skills and knowledges for PWR operations.

Nuclear Plant System Design - The Nuclear Plant Systems Design Program addresses the many subsystems that comprise the Westinghouse PWR. This program is based upon ten core courses addressing such topics as: electrical systems; reactor system and components; reactor support systems; engineered safeguard systems; steam cycle systems; steam cycle support systems; control and protection instrumentation systems; and integrated system operation and response. As one would surmise, the purpose of the program is to provide the student the in-depth system description knowledge needed for operations. This is accomplished in a variety of manners including lecture, slide presentation, computer aided instruction, and tours of an operating plant.

Nuclear Plant Operations - As the title implies, the Nuclear Plant Operations Program focuses upon actual plant operations. A full scope simulator is used

to master the skills and knowledges of this program. The program has seven core courses addressing such topics as: technical operating specifications, normal plant operations, transient responses, minor plant casualty training, and major plant casualty training. Upon completion of this program, the student is capable of plant startup and operations, including casualty analysis and response, as judged by simulated control board performance.

Thus, the Westinghouse model represents an articulated sequence of programs and courses designed to prepare competent operations personnel as verified by their actual performance against measurable objectives. It is the culmination of properly sequenced objectives presented via a well integrated combination of theory and hands-on application.

SUMMARY

In conclusion, Westinghouse Nuclear Training Services has implemented an analytical, logical, and proven process to develop its curriculum. The resultant curriculum model and materials represent a comprehensive and articulated approach to nuclear power plant operator training. This concern for quality training represents one significant commitment for the overall safety and efficiency of the nuclear industry.

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